Appendix 2

Emerging Markets in Water and Investments in Institutional Reform

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A Comparative Analysis of the
Central Valley Project and the Colorado-Big Thompson

Working Paper

by

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I. Introduction

Given the high cost of new water supply projects and continued increases in water demand, existing water supplies will have to be used more efficiently in the future. Well-functioning water markets are a key to more efficient use. They can provide water users with more short-run flexibility to adjust to volatile weather conditions and more long-run flexibility to adjust to shifts in production technology and consumer preferences. Unlike more traditional non-market water allocation systems, market-based systems confront users with the real opportunity cost of water and create incentives for water to be used in its highest value use. Given the potential gains from trade for both buyers and sellers, market-based systems of water allocation are gaining broader acceptance among a wide array of groups--urban, agricultural, and environmental.

In California, pressure is building to reallocate water from Central Valley farmers to municipal, industrial and environmental uses and to develop mechanisms to protect in-stream flows and water quality. In 1992, President Bush signed the Central Valley Project Improvement Act (CVPIA), which attempts to eliminate some of the obstacles to private water sales and also allocates 800,000 acre-feet of water annually to the environment. Impetus for the CVPIA came from the five-year drought that began in California in 1987. The drought also triggered the development of the emergency State Water Bank in 1991. While developed as a temporary drought-relief measure, the Bank is now a permanent component of California water policy. Despite these reforms, institutional barriers still prevent many water trades from occurring and increase the cost of trades which do occur. As a result, actual market activity is still limited. In contrast to the CVP, active water markets between agricultural and urban areas have developed in Colorado's Big Thompson Project (C-BT). The allocation of water in the C-BT is governed by a different set of institutions which enable market transactions to occur at a relatively low cost. This paper compares the water allocation institutions in the CVP and C-BT and attempts to explain their evolution.

The analysis demonstrates the importance of institutional path dependence. While the CVP and the C-BT were contemporary projects with similar objectives, the institutions which were developed to allocate water were significantly different. The institutional choices made in the early stages of each project were constrained by pre-existing property rights systems and organizational structures. The choices were motivated by the short-term goals of building consensus between diverse interest groups and obtaining financing for construction, but they have had long-run impacts. Due to network externalities, returns to scale and the quasi-irreversible nature of institutional investment, the organization and performance of the CVP and the C-BT today reflect the institutional paths chosen in the past.

The analysis of the CVP and C-BT is used to motivate a predictive model of institutional reform. The model demonstrates that investments in institutional reform are incremental, building from the existing set of institutions. Investments in reform may be delayed longer than would be predicted by traditional cost-benefit analysis, but this delay may be a rational response to uncertainty, irreversibility and the ability to wait for more information. An investment in institutional reform can reduce the transaction costs associated with water trading, but the benefits of reform must be weighed against the costs. The costs of reform include the fixed costs of reaching a consensus among diverse interest groups and the adjustment costs associated with learning new rules and regulations.

The paper is organized as follows. Section II provides a brief background on the institutions used to allocate water in the CVP and the C-BT. Section III compares the water markets which have evolved in each project and analyzes how the institutions which govern water allocation effect the organization and performance of the markets. Section IV attempts to explain the origins of the institutional and organizational differences. Section V develops a predictive model of institutional reform which can be applied to the CVP and the C-BT.

II. The Water Allocation Systems

Water Districts

In all reclamation water projects, the Bureau holds the appropriative right to the water it diverts. It enters into a service agreement with a delivery entity, often called a water district, and the delivery entity forms long-term contracts with the individual water users. The contracts grant the users a set share of the overall supply and entitle them to continued delivery by the federal government throughout the duration of the contract. Most contracts are for forty years. The governance of reclamation projects is complicated by the duel authority of federal and state governments. A reclamation right is fundamentally a state-granted right, and thus the state plays an important auxiliary role in Bureau projects. In early court cases, federal law was usually seen to override state law, but in the case of *California vs. U.S.* (1978), the Supreme Court ruled that the CVP is subject to State Water Resources Control Board (SWRCB) jurisdiction.[1] The boundaries of state verses federal authority have never been clearly defined, however, and as a result the rules governing Bureau water projects are often inconsistent and unpredictable.

The rules which govern the CVP are especially complex because the Bureau contracts with over 40 separate water districts. Some of the water districts were established long before the CVP was built, with the initial purpose of building and operating local water irrigation projects. Others were established much later with the explicit purpose of contracting with the Bureau for CVP deliveries. The water district entitlements range from a few thousand acre feet to over a million acre feet per year. In addition to contracting with water districts, the Bureau contracts directly with riparian landowners who held prior claims to the water diverted by the Bureau. Each contractor has its own unique contract. CVP water users may unite to protect agricultural interests against urban and environmental

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[1] The case arose when the Bureau applied to the SWRCB for a permit to appropriate water that would be impounded by the New Melones Dam, a unit of the CVP. After lengthy hearings, SWRCB approved the Bureau's application but attached twenty-five conditions to the permit, which it concluded were necessary to meet California's statutory water appropriation requirements (Reisner).

interests (since the vast majority of CVP water is used in irrigation), but they also lobby for their own local interests.

In contrast to the CVP, there is only one water district in the C-BT. The Northern Colorado Water Conservancy District (NCWCD) was established in 1937 to be responsible for guaranteeing the repayment of project costs, negotiating solutions to conflicts with the basin of origin and allocating water among users with various needs. The NCWCD serves agricultural, municipal and industrial users, and is responsible for achieving compromises between these diverse groups. The delegation of power to a single water district provides the C-BT with a more coherent and rational governance structure than the CVP [1].

Priority vs. Proportional Rationing

If the supply of water were constant each year, surface water rights would be relatively easy to define. However, water supplies depend on stochastic weather conditions; therefore, a non-market water allocation system, which does not rely on prices to equate demand with supply, must develop a rationing mechanism. Water in the CVP is rationed according to a priority system. In the event of a drought, senior-rights holders receive supplies before junior-rights holders. Land associated with senior rights is said to have "higher priority." Landowners who held riparian rights before the CVP was built have the most senior rights. Next in line are the irrigation districts which formed in the wake of the 1887 Irrigation District Law and which contracted early with the Bureau for CVP water. Junior rights belong to districts which contracted with the Bureau later.

In addition to varying between water districts, user priorities may also vary within CVP districts. For example, Westlands Water District has junior water rights relative to other districts in the CVP, but within Westlands there are also different priority areas, ranked I, II, and III. Priority area I encompasses 337,000 acres of land which was part of the original Westlands water district. Under a 1963 contract with the Bureau, this area is entitled to 900,000 acre-feet of water in full-delivery water years or 2.6 acre-feet per acre.

Area II covers 187,000 acres of land which was annexed by Westlands at a later date from the former Westplains water district. This area is entitled to 250,000 acre-feet or 1.3 acre-feet per acre. Area III covers an additional 10,000 acres which was annexed to Westlands after the merger with Westplains. In the event that full deliveries cannot be met (which has been the norm rather that the exception in recent years), water is rationed first to Area I land and then to Area II. Land in Area III only receives water in the event that the needs of both Areas I and II have been met [2].

In the C-BT, water is rationed according to a proportional system. The C-BT is designed to deliver 310,000 AF in a full delivery year. The NCWCD divided the water into 310,000 individual "allotments" which are transferable contracts between the district and the holder, subject to the holder's ability to show beneficial use of the water within the boundaries of the district. If the C-BT delivers less than the full 310,000 AF in a given year, supplies to all users are cut back proportionally [3]. For example, if the aggregate supply is reduced by 10% to 279,000 AF, then each individual's supply will be reduced by 10%. If a user owns 100 allotments and thus receives 100 AF in a full-delivery year, he or she will receive 90 AF.

The next section compares water market activity in the CVP and the C-BT. The organization and performance of the water markets are a function of the allocation mechanisms used. The cost of trading is lower in the C-BT because it has a unified conservancy district, which serves agricultural, municipal and industrial users, and because its water rights are based on a system of transferable allotments and proportional rationing.

III. A Comparative Analysis of Two Evolving Water Markets

CVP

Most water market activity within the CVP is limited to internal water district trades. The contracts between individual farmers and the water districts in the CVP entitled farmers to use a set amount of water on a given piece of land. They did not provide individual

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farmers with the explicit right to transfer their entitlement to another farmer or even to change the nature of its use on their own land without approval [4]. The CVPIA lifted many of the restrictions on water transfers, but trades between water districts require approval from the Bureau and/or SWRCBD. The rules which regulate transfers depend on whether the parties to a transaction have riparian, pre-1914 appropriative rights, post-1914 appropriative rights, or more junior contract rights. Water users must demonstrate that the water will be put to beneficial use in the new location. Transfers are not approved if they will have a significant long-term adverse impact on groundwater conditions within the basin of origin, or if they will unreasonably impact the water supply, operations, or financial conditions of the supplying district [5].

Despite the difficulties of trading between water districts, intra-district water trading is relatively routine and only requires the approval of the water district. Intra-district transfers are short-term "rental" transactions in which the buyer receives the right to use a specified amount of water during the current season. Markets in which permanent water rights are bought and sold do not currently exist. While the local rental markets may help farms adjust to short-run fluctuations in supply and demand, the gains from trade within water districts may not be large if the farms are relatively homogenous. Especially within small water districts, farms may have comparable water rights and soil types, grow the same crops and use similar technologies.

The gains from trade between water districts are potentially much greater, because there are large variances in farm productivity and water rights across districts. Districts with senior rights have larger contract entitlements (in terms of AF per acre) than districts with junior rights. In addition, the difference in supplies increases during dry years due to the priority rationing system. Thus, the potential gains from trade, or alternatively the opportunity costs of restricting trades, increase during dry years. Given that the approval process associated with inter-district trades can be complicated and time-consuming, most of the inter-district trades which do occur are negotiated by water district staffs on behalf of their farmers rather than directly by the farmers themselves. The trades are short-term transfers of water use as opposed to permanent transfers of water rights. Some trades between districts in the CVP and water districts outside the CVP have also occurred but they require additional layers of regulatory approval.

The most active local water market within the CVP is in Westlands Water District. The conditions in Westlands set it apart from the other water districts. Most notably, it is the largest district in the CVP, with approximately 600 farms covering nearly 600,000 acres. In addition, farms within the district have heterogeneous water rights, and the junior water rights are often associated with the most productive land. Due to the size of the district, and the heterogeneity across farms, the opportunities for trade are greater in Westlands than in other districts. Even though the market in Westlands is more active than in the other districts, it is still ad hoc. There are no centralized trading locations and no publicly posted market prices. To reduce the search and negotiation costs associated with market transactions, farms make supply adjustments by transferring water internally within their farm management unit[2] instead of in the market. These internal transfers are analogous to movements of inputs between factories within the same firm. If farms do trade in the market, they tend to trade in networks in which they trade repeatedly with a core group of farms.

In March, 1996, researchers from the University of California at Berkeley and Davis established an electronic marketing system in Westlands, called WaterLink. The goal of WaterLink is to reduce the search and transaction costs associated with participating in the market. WaterLink enables farms to advertise water-wanted or water-for-sale on an electronic bulletin board and to negotiate with other farms and the water district via email. Use of WaterLink is increasing gradually, but most farms have continued to rely on internal transfers or transfers between familiar trading partners instead of trying to find new trading

[2] See discussion below on farm management units and the acreage limitations imposed under reclamation law.

opportunities through WaterLink. The value of WaterLink would increase if it linked farms in Westlands with farms in other districts, because both the gains from trade and the costs of search and negotiation would increase in an inter-district market. It is only a matter of time before the Bureau and the water districts negotiate the institutional reforms necessary to make inter-district markets possible. Preliminary negotiations to expand WaterLink to other districts have begun, but the incentive necessary for the groups to reach an agreement may not exist until there is another dry year [2].

The drought in California from in 1987 and 1992 triggered institutional reforms which aimed to increase water transfers. The state established the emergency drought Water Bank in 1991 which generated some transfers from areas with low-value uses to areas with high-value uses. The state bought 810,400 AF of water from sellers at $125 per AF. The purchase price of water was $175 per AF (approximately $40 of the difference was used to pay for carriage water to provide salt protection in the Sacramento Delta, and $10 was used to pay administrative fees). However, when transportation fees were added, the delivery price of water in some areas was as high as $230 per AF. At this high price, only 390,400 AF of water was purchased. Urban areas accounted for three fourths of the purchased water and farmers growing high-value fruit, vegetable and nut crops accounted for the remaining third. In addition to the amount purchased, 120,000 AF was used as carriage water through the Delta. The remaining 300,000 AF of water was carried over for the 1992 Bank [6]. Since 1991, the Bank has evolved from a fixed-price structure to an options structure in which water users can by water options which may be exercised if drought conditions prevail.

Also in reaction to the drought, Congress passed the CVPIA in 1992. Drought conditions heightened public awareness of the allocative inefficiencies of the CVP. The Act requires 800,000 acre feet to be reallocated from CVP users to in-stream flows to protect damaged habitat. The Act also reduces restrictions on water transfers by granting the right to individual water users to sell their water rights. While water rights transfers between

CVP users and municipalities outside the CVP are now theoretically possible, to date no transfers have been completed. One farmer did attempt to negotiate a deal with a municipality but neighboring farmers adamantly opposed the trade. They argued that the transfer would negatively impact local groundwater aquifers.[3] Because an active market in permanent rights does not exist, a farm which sells its water right is making an irreversible disinvestment. Given uncertainty about the future value of water, which is driven by political and demographic factors as well as stochastic weather patterns, a farm's *option* to sell its water is very valuable, and farms may wait a long time before exercising their option to sell.

The immobility of water limits the ability of farmers to adapt to short-run supply variations. In the event of shortages, senior rights holders may still receive their full entitlements while junior rights holders may not receive any water. Thus, senior rights holders are insulated from supply shortages and, given that they cannot sell their water to junior rights holders, have little incentive to cut back their use. To the extent that senior rights correspond to high-valued uses for which security of supply is crucial and junior rights correspond to low-valued uses for which security is not crucial, the priority system may be an efficient method of allocating scarce supplies. However, such a relationship does not necessarily exist. For example, Westlands is a low *priority* water district, but it is a high *productivity* district. In addition, within Westlands, much of the highest productivity land is located in priority area II and not in area I. In addition to failing to allow for efficient responses to short-run supply fluctuations in the agricultural sector, the institutions and laws which govern the CVP inhibit long-run adjustments to changes in economy-wide water demand.

[3] When farms apply water, only a percentage of the water is used by the crop, and the remaining water either evaporates, recharges groundwater aquifers or returns to neighboring streams. The water that returns to the groundwater aquifer or stream may provide a positive externality to neighboring farms. Therefore, if a farm sells its water instead of using it for irrigation, neighboring farms may be adversely impacted.

C-BT

In the C-BT, both allotment rental markets and allotment sales markets exists. In addition, trades occur not just within agriculture but also between the agricultural and urban sectors. If water allotment owners have excess supplies in a given season, they can rent their water to another water user within NCWCD. In addition, while the transaction costs are higher, C-BT water can be rented to users not on the NCWCD delivery system through a system of exchanges and replacements. Rentals of non-C-BT water also occur within and between ditch companies. Non-C-BT rentals usually entail higher transaction costs than C-BT rentals, however, because conveyance costs are higher and because they involve different liability rules for third-party effects than internal C-BT transfers.

The NCWCD staff facilitates rental exchanges by putting prospective rentees and renters in contact. Occasionally an auction of rental water will be advertised, but in most cases the parties to an exchange settle on a price among themselves. In an average year, about 30 percent of the C-BT water delivered to the district is involved in rental transactions. In general, the agricultural sector is a net rentee and cities are net renters of water, although cities have begun to use more of their allotments each year in response to population growth [7]. In recent years, brokers have begun to participate in the rental and sales markets. Some brokers simply link up interested buyers and sellers, but others act as speculator-sellers. The later type must own agricultural land, on which he or she can demonstrate beneficial use. When opportunities to buy arise, the broker can then either use the water to irrigate crops temporarily or he or she can rent it until a buyer is found.

When two parties want to transfer an allotment right, they must submit an application to the district so the district can verify that the water will be used beneficially. The approval process is intended to safeguard against speculative purchases of allotments. Municipal and domestic water company users are usually exempted from the approval process, presumably because reasonable beneficial use is harder to define for nonagricultural uses. Rental prices tend to be well below water allotment prices, reflecting the fact that rentals carry a higher risk of non availability than allotments. In addition to risk factors, unwritten rules of conduct between cities and agricultural renters exist which suppress rental prices. The NCWCD directors have allowed cities to own allotments in excess of average use under the rationale that cities must have reliable supplies. However, in return for this privilege, it is implicitly understood that cities should not profit from rentals. Most towns simply add a small administrative fee to their variable cost when setting the rental price. In order to force renters to bear the true social costs of water use, the NCWCD should probably allow cities to charge a market price.

The C-BT's transferable allotment system has enabled northern Colorado to adjust to short-run and long-run shifts in water supply and demand. In response to urban and industry growth on the eastern slopes of the Rocky Mountains, NCWCD water allotments have been transferred from agriculture to municipal and industrial uses. Irrigators owned more than 85 percent of the water allotments in 1957 but only 64 percent in 1982. Actual water deliveries to nonagricultural uses are lower however, because cities and multipurpose users have tended to hoard extra allotments and rent water back to irrigators on a year-by-year basis. For example, while irrigators only owned 64 percent of the allotments in 1982, they used 71 percent of the available water [7].

Analysis of Transaction Costs

In both Colorado and California, transfers *between* water districts require a lengthy approval process. The cost of trading within the C-BT is lower because one district, the NCWCD, governs all C-BT water allocations. Since the NCWCD includes both agricultural and urban users, trades between these groups are possible at relatively low cost. In contrast, the CVP serves many water districts, each of which contracts separately with the Bureau. In addition, almost all of the CVP contractors are agricultural users, so transfers to urban sectors must go beyond the project's bounds which means additional regulatory complexity is involved.

Even if the rules governing transfers are modified to make it easier to obtain approval for trades between districts, some trades are restricted by physical factors. Necessary canals may not exist or it may be costly to obtain the rights to distribute the water. If a transfer requires use of distribution networks in multiple districts, permission must be obtained from each. In addition to capacity and coordination constraints, districts may have water quality concerns if a proposed trade involves pumping lower-quality water into the distribution system.[4] The absence of water metering devices can also limit trades. Some of the districts in the CVP (with junior rights) meter individual water use by the AF. Other districts (with senior rights) charge their water users a fixed per-acre rate, as opposed to a per-acre-foot rate, because they do not have metering devices to monitor individual use. The rate per-acre depends on the average water requirements of the crop grown. Suppose, for example, that the Bureau wants to generate $10 per acre on average, and suppose a farm grows 100 acres of cotton. If cotton production in the district requires 4 acre-feet of applied water per acre on average, the Bureau will charge the farm $40 per acre on 100 acres or a total of $4000. The farm will pay $40 per acre regardless of the actual amount of water it uses, as long as the farm's use is not flagrantly wasteful.

The measurement and enforcement costs of trading are high when districts do not meter individual water on a per acre foot basis. The majority of water users who sold water to the Water Bank in 1991 and 1992 were in districts with fixed per-acre rates. Because the costs of monitoring actual water use were prohibitive, the farms were required to fallow the land where the water would have been used.[5] For example, if the farm in the above example had wanted to sell 100 acre feet to the Bank it would have had to fallow 25

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[4] The Bureau ordered Westlands Water District to suspend its Groundwater Integration Program which allowed farmers to trade groundwater, because farmers in neighboring districts argued that the lower-quality groundwater reduced the overall quality of the water in the distribution system.

[5] Farms also had the option to substitute groundwater supplies for surface water supplies.

acres. If instead the district had the ability to meter the farm's water use by the acre-foot, the farm could have sold 100 acre feet and continued to produce 100 acres of cotton if it invested in modern irrigation technology which allowed it to produce cotton with 3 acre-feet of applied water per acre. With metering, farms have more flexibility and thus they are more likely to participate in the market. In addition, the negative impacts on the local economies of water exporting regions may be lessened if farms have the option of conserving water through investments in modern irrigation technology and better management practices instead of through crop fallowing.[6]

The priority system increases the transaction costs associated with trading by creating heterogeneous rights which must be quantified and priced for each individual trade. First, the price paid to the Bureau for an acre foot of water depends on the seniority of the water right, *i.e.* on the water contract type. Second, the likelihood of receiving a full-delivery is greater the more senior the water right. Third, the seniority of the right technically is attached to the land where it is used. Thus, if a right is traded to a user with land in a lower priority area, the seniority of the right may change as a result of the trade. Since markets in permanent water rights do not currently exist in the CVP, it is unclear how this would work. If the Bureau has to resolve the issue of seniority on a case by case basis the costs of trading will remain high.

In the intra-seasonal spot market, there is no uncertainty regarding supply availability. The Bureau announces its deliveries at the beginning of the water year so all users know how much they have in their annual accounts. A rental transaction is only approved by a water district after it has confirmed that the seller actually has the water in his or her account. However, trades are affected by the seniority of the water through the

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[6] However, to the extent that a significant number of farms adopt modern irrigation technology in order to sell their conserved supplies, the negative impact on groundwater aquifers may increase. Modern irrigation technologies allow farms to obtain a given yield with less water, but as a result there is less runoff back into the soil and/or neighboring streams. The transfers will thus impose a negative externality on neighboring farms which pump from the same aquifer. To internalize the externality, a per-acre tax could be levied on the seller.

price. The full market price is the Bureau water rate plus the transfer price paid by the buyer to the seller for use of the water. Since the Bureau water rate depends on the contract type (*i.e.* the seniority) the transfer price also depends on the contract type. Therefore the price paid by the buyer to the seller is specific to the contract type and the location of the trade. If a trade in permanent water rights were to occur, the buyer and the seller would have to consider the added complexity of supply uncertainty when valuing the right. The value of 100 acre feet of water depends on the seniority of the right and the user's expectations about future supply. Clearly 100 acre feet of senior-right water is worth more than 100 acre-feet of junior right water, because in a given year the expected supply actually received is higher for the senior-right water. In a drought, the owner of the senior right may still receive full supply while the owner of the junior right may receive nothing at all.

The C-BT's proportional rationing system lends itself more easily to the creation of a water market because the property rights are homogenous. A user's expected supply in a given year, just depends on the number of allotments he or she owns or rents. It does not matter from whom the user buys or rents an allotment or where the water is used as long as it is within the NCWCD boundaries. The cost of trading C-BT water is further reduced by the district's return flow rule. The right to C-BT return flows was granted to the NCWCD under the argument that the water diverted by the C-BT was new to the east slope of the Rocky Mountains. Outside the NCWCD, return flows are governed by Colorado prior appropriation law, which grants downstream users the right to return flows. The decision to grant ownership of return flows to the water district instead of to downstream users, proved to be instrumental in reducing the transaction costs associated with C-BT water trades. Simple buyer-seller market transactions of C-BT water can take place without worrying about return-flow interdependencies, because downstream parties have no legal grounds for objection. The return-flow provision frees C-BT water from many of the legal obstacles which stifle transfers in the CVP; however, by ignoring the impacts on third parties, inefficient transfers may be allowed to take place. The return-flow rule thus trades one hazard for another [8].

Another significant factor affecting the viability of market activity in the CVP versus the C-BT is the farm acreage limitation, stipulated by the Reclamation Act of 1902. Farms in the CVP are technically subject to the law while farms in the C-BT are not [1]. According to the original Act:

> No right to the use of water for land in private ownership shall be sold for a tract exceeding one hundred and sixty acres to any one landowner (i.e. a single family), and no such sale shall be made to any landowner unless he be an actual bona fide resident on such land, or occupant thereof residing in the neighborhood of said land, and no such right shall permanently attach until all payments thereof are made [9].

The acreage limitation was intended to promote family farming, but the law failed to achieve this goal. First of all, 160 acre farms which may have been viable in the eastern half of the country were not profitable in the semi-arid west. Second, by the time the CVP was constructed, the majority of the land to be served by the project was already in private holdings larger than 160 acres. Abuse of the acreage requirement ranged from allowing a husband and wife each to hold 160 acres, and thus increase a farm's size to 320 acres, to out and out violations. In 1982, the Bureau increased the allowable acreage to 960 acres and, in exchange for relaxing the acreage limitation, vowed to enforce the rule. However, large farms were able to satisfy technical compliance with the law by distributing 960 acre plots to individual family members and creating family trusts or "farm management units."

Even though the federal government has never strictly enforced the acreage limitation law, the law has deterred transfers in the CVP in two ways. First, the law is yet another factor which increases the heterogeneity of water rights, because the value of a given right is a function of the size of the farm on which the water is used. The 1982 amendment allows farms to receive project water on land in excess of 960 acres but the farm must pay a higher price ("full-cost") for the water to the excess land. Thus the acreage limitation, along with the seniority system, forces the buyer and the seller to consider the location of water use in addition to the quantity being transferred.

Second, the law has contributed to the perception among farmers that their rights are insecure. From the CVP's early days to the present, abuse of the acreage limitation has been a focal point of critics of the CVP and other Bureau projects. The stated intent of the reclamation projects was to provide new opportunities for family farming in the west but instead, critics point out, the projects have provided subsidized water to large corporate farms at taxpayer expense. In the same way that farm lobbies have been able to use political might to stave off the law until now, farm lobbies realize that urban and environmental interest groups may be able to wield their increasing power to force changes which jeopardize their rights. Given this political uncertainty, farmers may be hesitant to participate in water market transactions. Even though the "use it or lose it" rule has been amended to allow farms to sell conserved water, by selling their water, even on a short-term basis, they will be demonstrating that the water is not essential to them, and this could be used against them in the future. Further, in a well-organized market prices will be publicly available, and the extent of the federal subsidy farmers receive through low water rates will become more obvious to the general public. Many districts in the CVP recently had to renegotiate their contracts with the Bureau, because their 40 year contracts were up. These districts were probably especially careful to demonstrate a need for all of their water. To the dismay of many environmentalists and urban groups, all of the districts successfully renegotiated their contracts. Their rates were increased, but supply levels were maintained. Other districts still face the uncertainty of contract renewal. Westlands Water District's contract expires in 2007.

IV. What Accounts for the Institutional Differences?

Why did two Bureau of Reclamation projects, which were approved and built at approximately the same time and which share many common features, adopt very different institutional structures and mechanisms of governance? More specifically, why does the Bureau contract with over 40 water districts in the CVP and only one in the C-BT? Why is water rationed through a priority system in the CVP instead of through a seemingly more logical proportional system? Why is the C-BT not subject to the reclamation law acreage limitation rule and why do C-BT return flows belong to the NCWCD?

While many factors are important, I believe the following are essential. First, California's pre-existing system of water rights was more complex and confusing than Colorado's. Most importantly, the existence of powerful riparian landowners in California shaped the outcome of the CVP. Second, the CVP began as a state project, but when California could not finance the project, it was rescued by the federal government at the last minute. In contrast, Coloradans realized much earlier that they could not finance a transmountain diversion and that they must convince the federal government to build the project. Third, the C-BT's promoters marketed their project as a *supplemental* water supply which would serve both agricultural and urban areas, while the CVP water was a *primary* water supply that enabled hundreds of thousands of acres of new agricultural land to come into production.[7] The nature of the supply generated by the C-BT and the CVP, *i.e.* whether it was supplementary or primary, shaped the institutions which were created and it affected the treatment of the projects by the federal government. The impact of these differences is explored in more detail below.

[7] To certain audiences, the CVP's promoters also claimed their project would provide supplemental water. To stave off opposition from farmers who already possessed secure water supplies, and feared competition from new farmers, the CVP promoters claimed the project was a rescue measure to provide relief to land already under cultivation; however, this claim was tenuous in many areas.

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CVP: Institutional Evolution

Attempts to develop a comprehensive state-wide water project began in 1919 when Robert B. Marshall, a former member of U.S. Geological Survey, published an ambitious plan that would have delivered water supplies to the San Francisco Bay Area and Los Angeles as well as to the Central Valley. The plan failed to gain approval in the state legislature in 1919 and 1921. Three modified versions went on the ballot as initiatives and were rejected by the voters in 1922, 1924, and 1926. The State Engineer, Edward Hyatt, introduced a scaled back state water plan to the legislature in 1931. In addition to delivering water from the Sacramento Valley south to the San Joaquin Valley, the plan called for an aqueduct from the Colorado River to deliver water to southern California. Southern California had already begun efforts to secure Colorado River water on its own, however, and believed that involvement with the state would complicate its efforts. Therefore, it asked not to be included in the state project. With the omission of southern California, the state project became almost exclusively a Central Valley project with the goal of supplying water for irrigated agriculture. By 1931, California's major urban areas had already taken local action to secure water supplies. Los Angeles had already completed the Owens Valley project, San Francisco had completed the Hetch Hetchy project, and the East Bay cities had completed the Mokelumne River project [9].

The Central Valley Project was passed in the California state legislature in 1933, and then after an attempt by private electric power interests to block the project, it was reaffirmed by the voters in a referendum election later that year. The federal government provided emergency relief to the state and then took over the project completely when it became clear that California would not be able to sell the bonds necessary to finance construction. California had no choice but to turn the project over to federal government if it wanted the project to be built since the state's unemployment was at 20%, and the country was in the middle of the Great Depression. The fragmented governance structure of the CVP reflects its origins as a state project. In order to build the project, the state leaders needed to reach compromises with diverse local interests. Their task was made more difficult by California's complex system of water rights and its fierce water litigation legacy.

California water law accommodates both riparian and prior appropriation rights (as well as correlative, pueblo, and Indian rights).[8] California's dual rights system is largely a legacy of the landmark case of *Lux v. Haggin* (1886), which pitted riparian rights holder Henry Miller (Lux was Miller's partner) against prior appropriation rights holder James Haggin for control of the Kern river. After five years of litigation in the lower courts, the California Supreme Court ruled in favor of Miller and reaffirmed the right of a riparian on private land to demand undiminished flow of a water source. In reaction to the ruling,

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[8] *Riparian Rights*

The riparian doctrine, which preceded the prior appropriation doctrine, is the most common form used in the eastern United States. Under riparian law, landowners located along a river or stream can use as much water as they need to irrigate their fields, but they cannot divert water for use on lands outside the original watershed. When the riparian doctrine is strictly enforced, water rights may not be transferred to others for use on non adjacent lands. Thus, landowners without river-front acreage are excluded from surface water use. In areas where water supplies are abundant relative to demand, and thus there are fewer conflicts in use, riparian laws apply and usually are not enforced very rigorously (Zilberman, Reisner).

Prior Appropriation Rights

The prior appropriation doctrine is more common in the western United States where competition for scarce water resources is greater. In contrast to riparian law which is based on land ownership, appropriative law is fundamentally a usufructuary right. The appropriative right defines the time and place of water diversion, the place where the water is to be used and the type of use. If the appropriator wishes to change any dimension of the right, he must apply for a permit change with the state.

Under the prior appropriation doctrine, senior rights are granted to the first person or party to put water to "beneficial use" regardless of whether the land on which the water is used is contiguous to a stream. This is expressed as "first in time, first in right." The definition of beneficial use varies from state to state; however, traditional beneficial uses have included irrigation, livestock watering, industrial and domestic uses. Only recently state legislatures have included recreational uses and fish and wildlife habitat protection in the definition of beneficial use.

Once an appropriative right is established it continues to exist as long as the water is beneficially used. A right may be declared abandoned if the appropriator intentionally discontinues use for several years. Even if the appropriator unintentionally discontinues use for a period of time established by statute, the right may be forfeited. This is commonly called the "use it or lose it" rule.

An extremely important aspect of prior appropriation doctrine is its treatment of return flows. Under appropriation doctrine, return flows again become part of the stream and are subject to downstream appropriation. State laws attempt to protect downstream parties from the adverse impacts of changes in upstream water use patterns, including transfers among users, by requiring that upstream users advertise any proposed changes in points of diversion or types of use. Downstream parties who expect to be damaged by such changes are then permitted to petition the water court for relief. The court ordering process is costly prior appropriation rights holders formed an anti-riparian league and, in order to remedy their disadvantage against riparian farmers, lobbied for the right to use public funding to fund irrigation projects. In 1887 the Irrigation District Law (known as the Wright Act) was passed, permitting the formation of irrigation districts. The law declared that the use of water for irrigation provided a public benefit and thus deserved public funding. The irrigation districts were granted quasi-municipality status and therefore had the power to levy taxes in order to build public projects. By 1921 there were seventy-four irrigation districts in California, covering one third of all irrigated acres [10].

The supremacy of riparian rights over prior appropriation rights was strengthened in the case of *Herminghaus v. Southern California Edison* (1926) in which the California Supreme Court ruled that a downstream riparian can command the entire flow of a river to flood-irrigate land. The decision upheld a riparian's right to usurp the claims of an appropriator and use water in an unreasonable and wasteful manner. In response to public outcry over *Hermininghaus,* the California Constitution was amended in 1928 to require all water uses, not just prior appropriation uses, to be both reasonable and beneficial [9]. These cases, combined with others pertaining to ground water rights, pueblo rights and federal reservation rights, led to the system which has come to be known as "California Doctrine." California's combination of complicated, and often contradictory laws, influenced the mechanisms of governance used in the CVP.

To succeed in building the CVP, the project promoters needed the cooperation of the riparians and the senior appropriators. Depending on their location, some riparian landowners and senior appropriators were asked to accept project water in lieu of their previous supplies. In order for the senior rights holders to agree, they had to be convinced that their access to project water would be secure during drought years as well as wet years, and that their rights would be secure over time. Thus, the riparians were granted the

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and time-consuming and can lead to inefficiency in the transfer process to the extent that it prevents desirable transfers. There may be more efficient ways to address third-party hazards (Zilberman, Reisner).

"highest priority," the water rights were tied to the land and transfers were restricted. While support from the senior rights holders was essential, state leaders did not want to alienate the water irrigation districts. The irrigation districts were suspicious of central government and very protective of local interests. The CVP was shaped by efforts to solve the short-run problem of achieving the consensus necessary to begin construction. The least-cost solution was to build on the existing institutional system by protecting riparian seniority and the autonomy of the local irrigation districts.

C-BT: Institutional Evolution

The C-BT promoters were blessed with a more coherent water rights system. Colorado law only recognizes the prior appropriation doctrine. They also had a clearer vision of the project's objective: to provide a *supplemental* water supply to northern Colorado farms, municipalities and industries. While urban areas in California had taken local action to secure water supplies for future growth, Colorado had a smaller urban population base and fewer resources to develop local projects. Colorado sought federal aid to develop the water supply necessary to enable future urban growth. The goals of C-BT were therefore different than the goals of the CVP from the beginning.

Initially northern Colorado had attempted to secure rights to the North Platte River, but Wyoming and Nebraska were also competing for the North Platte flows. In 1933 the WPA decided to fund the Casper-Alcova project, which would enable Wyoming to store North Platte water upstream from Casper and develop 60,000 to 80,000 acres of land for irrigated agriculture. After approval of the Casper-Alcova project, northern Colorado began to seek an alternative supply source [3]. Colorado's defeat in the battle for the Platte River rights and the fight between the upper and lower basin states over water from the Colorado River, combined to instill a sense of urgency among Colorado water managers. They realized they needed to plan ahead for future urban growth and secure water rights before other states appropriated the water that flows out of Colorado. If Colorado did not

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act quickly to secure its water supplies, they believed other states would appropriate the flows necessary for future development.

When the C-BT backers initially started pushing the project it was during a period of falling agricultural prices and surplus supplies. Thus, there was a negative attitude toward projects which would bring more land into production. Because of this, they emphasized that the C-BT would provide supplemental water for future urban growth and agricultural land already under production. The proposed solution to northern Colorado's need for supplemental water was a transmountain diversion from the west slope of the Rocky Mountains to the east slope, originally known as the Grand Lake Plan. From an early stage northern Colorado representatives realized that a transmountain diversion would require federal aid. In order to promote the project in Colorado and convince the federal government to build the project, they established the Northern Colorado Water Users Association (NCWUA) in 1934 which represented 80 irrigation districts in 6 counties [3].

Colorado's initial application for funding from the Bureau was denied in 1936, and this failure convinced C-BT promoters that they would not win federal support until they achieved two goals: First, they had to convince the government that they had the ability to repay the government for construction of the project. Second, they needed to overcome opposition to the project and present a unified front to Congress. The project faced strong opposition from landowners on the west slope of the Rocky Mountains, and it faced opposition from the National Park Service and environmentalists because the plan called for a tunnel to be built through a section of Rocky Mountain National Park. Senior appropriators and successful irrigation districts on the east slope also opposed the plan because they did not want new acreage to come into production when agricultural prices were already extremely low.

The Northern Colorado Water Conservancy District (NCWCD) was established to achieve the first goal of repayment of federal loans. While the NCWUA represented the local irrigation district in negotiations with the federal government, under the existing institutional structure, each district would have to contract separately with the government. Further, unlike California's irrigation districts, Colorado's irrigation districts did not have the power to levy taxes. This posed a problem given that repayment might not be possible through water and hydroelectricity sales alone. C-BT promoters wanted to solve these problems by creating a single water conservancy district with the power to tax and contract with the government. In 1937, the legislature passed the Water Conservancy District Act, which stated that water conservancy districts could be established with the ability to tax. It was debated whether one conservancy district should exist for the whole state or whether there should be regional districts. Proponents of the regional district plan prevailed, because regional districts were perceived to be more politically palatable; however, conservancy districts had to contain both agricultural and urban land owners and satisfy minimum size requirements.

Achieving the second goal of widespread support for the project was more difficult. Representatives from the west slope, most notably Congressman Edward Taylor, argued that the project must provide an acre foot of water to the west slope for every acre foot provided to the east slope as well as additional storage capacity for west slope users. While east and west slope water users disagreed on the transmountain diversion project, they were united in their fear of losing Colorado water to the lower basin states, most notably to California. There was also a sense that they must seize the opportunity to access federal reclamation funds before the government committed all of its money to other western states. Northern Colorado backers of the transmountain diversion project tried to create a sense of urgency among all Coloradans. It required three years of negotiation, however, to work out a compromise which satisfied west slope representatives.

When individuals and municipalities petitioned for C-BT allotments, they had to prove that they already had an alternative water source. Because the water was supplemental, proportional rationing was both logical and feasible. It was logical because the NCWCD wanted the allotment rights to be transferable to allow for adjustments in

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growth, and proportional rationing made the allotments homogenous. It was feasible because the C-BT water supplemented existing water supplies. Senior appropriators would not have agreed to a proportional system if they had been expected to substitute proportional C-BT rights for their pre-existing rights; however, as a supplement to their existing rights, the proportional system was more acceptable. Once large landowners learned that the C-BT would be exempted from the 160 acre limitation rule, they realized the project could benefit them [3].

The Colorado congressional delegation argued that the C-BT should be exempt from the 160 acre limitation because the water would provide a supplemental supply to an

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area already developed.[9] California tried to make the same argument when the Bureau took over the CVP, by claiming that it was a "rescue project" to provide water to established farms which were suffering due to drought and depleted groundwater supplies, but it failed to convince Congress. In both Colorado and California, the land to be served by the projects was already in private hands, the majority in holdings significantly larger than 160 acres, and much of it lay fallow during all but the wettest years. The following factors may explain Colorado's successful effort to receive an exemption and California's failure. First, the C-BT supply really was more supplemental than the CVP supply. In order for petitions for C-BT allotments to be accepted, water users had to prove to the NCWCD that they had a primary water supply. Given Colorado's fear of losing water to the lower basin states, especially California which had a much larger population and more political might, it wanted to secure water for *future* water development. Colorado's urban areas may not have needed the C-BT water at the time, but they bought allotments to allow for future growth. In contrast, the CVP provided a primary water supply most of its users, some of whom previously only had access to a depleted groundwater supply. Second, Colorado had been working with the Bureau from the initial surveying stage of the project, and from the beginning Coloradans had promoted the project as a supplemental supply. In contrast, California was bailed out by the Bureau at the last minute. Given that it was being "rescued" it held a weak negotiating position. Third, the CVP was a much larger project requiring more federal funding. Eastern representatives in Congress would only support such a massive project if it believed the CVP would open up new areas for small family farms rather than benefit large landowners.

Current Pressure for Reform

As the demand for water in municipal and industrial sectors continues to grow, and the need to maintain in-stream flows is recognized, society will have to choose between

[9] Users on the Truckee project in Nevada were also exempt.

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investing in expensive new water supply projects or investing in the institutional reforms necessary to enable water transfers from lower-valued to higher-valued uses. A desirable system of property rights and governance mechanisms would present users with a predictable set of rules and policies which guarantee security of tenure while still allowing flexibility. It would allow prices to rise to reflect the true social costs of resource use, and it would minimize measurement and enforcement costs by defining homogeneous rights.[10] Further, it would protect third-parties from the adverse consequences of water transfers or changes in use, it and would include safeguards to protect the environment [8]. The C-BT outperforms the CVP in all categories except in protecting third parties and the environment. By ignoring the impacts of transfers on return flows, the C-BT reduces the legal costs of water transfers, and while the *overall* benefits may outweigh the costs, in some cases the costs of ignoring impacts on third parties may be high. The return-flow issue needs to be addressed. In addition, reforms are required in both California and Colorado which will increase the environmental sector's ability to purchase water for in-stream flows.

V. Model of Institutional Reform

The following model analyzes society's decision to invest in market institutions which can lower the transaction costs of reallocating water through markets. Institutions are broadly defined. They may include well-defined, transferable property rights, communication networks which reduce search costs between buyers and sellers and enable dissemination of market prices, metering devices and routine trading procedures. Just as capital is an input in a production process, institutions are thought of as "inputs" which

[10] Rights may be heterogeneous in the sense that there may be permanent rights, rental rights, option rights, and so on as in other markets. This type of heterogeneity, in which there are broad classes of contract types, is distinctly different from the extreme heterogeneity within the CVP, in which contracts vary from one individual to the next depending on seniority and land location.

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enable markets to function. By considering marginal increases to an existing stock of institutions, the model attempts to capture the incremental nature of institutional reform.

Society must pay a sunk cost in order to invest in additional market institutions.[11] In addition to costs which increase linearly with the size of an investment, there may be fixed costs and costs which increase non-linearly as the rate of investment increases. The payoff of an investment in additional market institutions is uncertain because the payoff depends on future gains from trade which depend on a stochastic water supply. Due to the irreversibility and uncertainty associated with institutional investments, society will wait until the expected present value of investment is greater than the investment cost. Traditional cost/benefit models of investment, which argue that an investment should be undertaken as soon as the expected present value equals the investment cost, result in incorrect predictions about the rate of investment. This model, which accounts for irreversibility and uncertainty, may provide insight into why water allocation mechanisms have been slow to change, even though the benefits of reform appear to outweigh the costs.[12]

The Model

If the marginal value of water varies across users, there are potential gains from trade. The marginal gain from trade can be represented in terms of an inverse demand function

$$P = D(Q, X),$$

where P is the marginal gain from trade, Q is the quantity of water that is reallocated through the market, and X is a stochastic shift variable representing the excess demand for

[11] In this model, the actor is a social planner who is assumed to maximize aggregate social welfare. In future versions of this paper I would like to consider a more realistic decision making process which involves negotiation between the agricultural, urban and environmental sectors. However, more realistic model which addresses issues of political economy is difficult within the stochastic, dynamic framework. Essentially the problem becomes a stochastic, dynamic game.

water. This is an instantaneous demand function at any given time t, however the time subscripts have been suppressed in this and other functions for notational ease. A zero value of Q corresponds to the initial water distribution resulting from the non-market allocation mechanism. If $P = D(0, X) > 0$, there is value to being able to redistribute water through a market. If the cost of trading is zero, water will be traded in the market such that the marginal value of water is equal for all users. Let Q^* be the optimal amount of water traded. Then $P = D(Q^*, X) = 0$, i.e. at Q^* the marginal gains from trade are zero. If the cost of trading is positive, the optimal level of trading will be less than Q^*.

Increases in the excess demand for water, X, shift the demand curve out and increase the marginal gain from trade for any given Q. X is assumed to follow a geometric Brownian motion with a positive drift rate α

$$dX = \alpha X dt + \sigma X dz ,$$

where dz is the increment of a Wiener process.[13]

The area under the demand curve is the total benefit of trading, or the total gains from trade

$$B(Q, X) = \int_0^Q D(q, X) dq .$$

The marginal benefit is

$$B_Q(Q, X) = D(Q, X).$$

If there are positive transaction costs, the benefits of reallocating water through a market must be weighed against the costs. Let the total cost of trading Q units of water

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[12] The model is adapted from models in chapters 9 and 11 of Dixit and Pyndick [11].

[13] Percentage changes in x are normally distributed. Thus $y = lnx$ is normally distributed. For information on Wiener processes, see Dixit and Pindyck, pp. 63- 82.

be $C(Q, M)$, where $C_Q(Q, M) > 0$ and $C_{QQ}(Q, M) \geq 0$. *M* is the control variable representing society's "stock" of market institutions. When society increases its stock of *M*, for example by introducing well-defined, transferable property rights, it will be said to increase its "market capacity" much like a firm increases its production capacity through increases in its stock of capital. Increases in *M*, shift $C_Q(Q, M)$ downward, and thus the marginal transaction costs associated with a given level of *Q* fall.

The social planner chooses *M* to maximize the net benefit of trading

$$N(M, X) = \max_Q \left[B(Q, X) - C(Q, M) \right],$$

where *N(M, X)* is a concave function in *M*. From the first order condition,

$$B_Q(Q, X) = C_Q(Q, M),$$

one can solve for the optimal number of trades as a function of *M* and *X*, and substitute $Q(M, X)$ into the net benefit function

$$N(M, X) = B(Q(M, X), X) - C(Q(M, X), M).$$

Then by the Envelope Theorem,

$$N_M(M, X) = -C_M(M, X)$$

which says that the marginal benefit of additional market capacity is the resulting decrease in the cost of trading.

An Example

Suppose there are only two water users in the economy, "Ag" and "Urban." As shown in Figure 1, let S be the total supply of water to the economy at time t, and let the water be allocated such that Urban receives s_0^1 and Ag receives s_0^2 (point s_0). At the initial allocation, the marginal benefit of water is greater for Urban than for Ag and thus there are potential gains from trade. If the cost of trading were zero, Ag would sell s_1-s_0 to Urban such that the marginal benefit of water to each equaled MB_1. The total gains from trade are given by area *abc*, which is the difference between the marginal benefit curves between s_0 and s_1. Area *abc* can be transposed into a graph in P - Q space, as shown in Figure 2. P is the marginal gain from trade, and Q is the quantity of water traded. The marginal gain from trade associated with a given X is given by $P = B_Q(Q, X)$, and the area under the curve is the total gains from trade $B(Q, X)$. $P_{\max} = MB_0^1 - MB_0^2$ and $Q_{\max} = s_1$-s_0.

Now suppose the excess demand for water increases to X'. This might occur if Urban's marginal benefit function shifts out due to growth in the urban sector, and/or if the aggregate supply decreases due to a drought. The dotted lines in Figures 1 and 2 show the effect of an upward shift in Urban's marginal benefit function. As shown in Figure 2, the marginal gains from trade $P = B_Q(Q, X')$ are now larger for any given Q.

In order to find the optimal amount of trading between Ag and Urban, the transaction costs of trading must also be considered. The optimal level of trading Q^* for a given X and M occurs where the marginal benefit from trading, $B_Q(Q, X)$, equals the marginal cost of trading, $C_Q(Q, M)$. This is shown in Figure 4. The net benefit of trading, $N(M, X)$, is represented by the area *cfg*. Figure 3 shows the equilibrium in terms of the marginal benefit curves of Urban and Ag. Instead of trading the amount s_1-s_0 to Urban as it would if there were no transaction costs, Ag only trades the amount s^*-s_0 to

Urban. At s^* the marginal benefit of Urban exceeds the marginal benefit of Ag by the marginal transaction costs $C_Q(Q^*, M)$.

If society invests in institutional reform, and increases M to M', the marginal cost curve will shift down as shown. This is shown in Figure 5. As a result of the institutional reform, the optimal level of trading increases from Q^* to $Q^{*\prime}$.

The Investment Decision

If society invests in additional market institutions M, it can reduce the transaction costs of trading. However, an investment in an additional unit of market capacity, requires payment of an irreversible cost κ, so the social planner must weigh the cost of investment against the benefit. If the level of excess demand X is low, the gains from trade will not be significant enough to justify investment, but once X rises to a critical level, the social planner will pay κ in order to increase M.

Let $W(M, X)$ equal the maximized value of the net benefit function. $W(M, X)$ is known as the Bellman value function. The expected value of an increase in market capacity from M to M' is

$$(1) \qquad W(M,X) = N(M,X)dt + e^{-\rho dt} E[W(M', X + dX)] - \kappa(M' - M),$$

where the first term is the known net benefit flow over the interval dt, the second term is the expected present value of the net benefit over all future t and the last term is the cost of the investment. The social planner will choose M' to maximize the right-hand side of this expression. The resulting maximum is the initial value $W(M, X)$ of the Bellman function.

Before formally solving the problem, I will outline the social planner's investment strategy in intuitive terms. Suppose the problem has been solved and thus $W(M, X)$ is known. Intuitively, no investment will occur if the benefit of institutional reform is less than the cost, i.e. if $W_M(M,X) < \kappa$. Therefore the curve $W_M(M,X) = \kappa$ will separate the region of inaction from the region of investment. The threshold curve is shown in Figure 6. The social planner will follow a "barrier control" strategy. If the point (*M, X*) initially lies below the curve but then *X* rises so that (*M, X*) hits the curve and tries to rise above it, the social planner will increase *M* just enough to keep (*M, X*) on the curve. If *X* falls, so that (*M, X*) drops below the curve, the social planner will stop investment until *X* rises to bring (*M, X*) back up to the curve again. If (*M, X*) initially lies above the curve (because of previously non-optimal policies or a shock to the curve), the social planner will instantly increase *M* in a discrete jump to bring (*M, X*) down to the curve. After the initial jump in investment, the social planner will either invest in small bursts if (*M, X*) is at the curve or will cease investment if (*M, X*) falls below the curve. The rate of investment is either infinite or zero, so the time path of *M* is nondifferentiable.

To solve the problem, I first consider the region of inaction when (*M, X*) lies below the threshold curve $W_M(M,X) = \kappa$. When $dM = 0$, the Bellman function takes the simple form

(2) $$W(M,X) = N(M,X)dt + e^{-\rho dt}E[W(M,X+dX)].$$

To solve this I note that

$$\begin{aligned} e^{-\rho dt}E[W(M,X+dX)] &= e^{-\rho dt}E[W(M,X)+dW(M,X)] \\ &= e^{-\rho dt}W(M,X) + e^{-\rho dt}E[dW(M,X)] \end{aligned}$$

The first term can be pulled out of the expectation since the current state (*M, X*) is known. Using Ito's Lemma,[14] the last term can be expanded as follows:

[14] See Dixit and Pindyck, pp. 79-81.

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\begin{aligned}
dW(M,X) &= W_X(M,X)dX + \tfrac{1}{2}W_{XX}(M,X)(dX)^2 \\
&= W_X(M,X)[\alpha X dt + \sigma X dz] + \tfrac{1}{2}W_{XX}(M,X)\sigma^2 X^2 dt \\
&= \alpha X W_X(M,X)dt + \tfrac{1}{2}\sigma^2 X^2 W_{XX}(M,X)dt + \sigma X W_X(M,X)dz
\end{aligned}
$$

Bringing the parts back together, and using the fact that E(dz) = 0, one derives

$$W(M,X) = N(M,X)dt + (1-\rho dt)\left[W(M,X) + \alpha X W_X(M,X)dt + \tfrac{1}{2}\sigma^2 X^2 W_{XX}(M,X)dt\right]$$

Keeping terms to order dt and rearranging

$$W(M,X) = W(M,X) + \left[\tfrac{1}{2}\sigma^2 X^2 W_{XX}(M,X) + \alpha X W_X(M,X) - \rho W(M,X) + N(M,X)\right]dt.$$

Therefore, $W(M,X)$ satisfies the differential equation

(3) $$\tfrac{1}{2}\sigma^2 X^2 W_{XX}(M,X) + \alpha X W_X(M,X) - \rho W(M,X) + N(M,X) = 0.$$

Given that *W* is a function of two variables, this is a partial differential equation; however, since it does not involve any derivatives with respect to *M*, it can be treated as an ordinary differential equation that links *W* to *X*. *M* can be viewed a parameter that shifts the whole functional relationship.

The general solution of the differential equation is

$$W(M,X) = B_1(M)X^{\beta_1} + B_2(M)X^{\beta_2} + PV(M,X),$$

where the third term on the right-hand side is defined as follows:

$$PV(M,X) = E\left\{\int_0^\infty N(M,X_t)e^{-\rho t}dt\right\}.$$

This is the expected present value of the net benefit from trading that would result if *M* were kept constant at its initial value forever and X_t followed its stochastic path starting

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from the initial value X. β_1 and β_2 are the positive and negative roots of the fundamental quadratic,

$$Q \equiv \tfrac{1}{2}\sigma^2\beta(\beta-1)+(r-\delta)\beta-r=0,$$

and $B_1(M)$ and $B_2(M)$ are "constants" of integration which must be determined. The "constants" of integration are functions of M, rather than true constants. To solve for the three unknowns, $B_1(M)$, $B_2(M)$ and the threshold X^*, I use the boundary conditions. The region of no reform includes the boundary where X goes to zero. Since β_2 is negative, $B_2(M)X^{\beta_2}$ goes to infinity as X goes to zero. Therefore, to keep $W(M, X)$ from exploding, $B_2(M)$ is set equal to zero, and the solution is simplified to

(4) $$W(M,X)=B_1(M)X^{\beta_1}+PV(M,X).$$

The remaining constant $B_1(M)$ and the threshold X^* are determined using the conditions at the boundary between the region of inaction and the region of investment. As discussed heuristically above, the curve $W_M(M,X)=\kappa$ divides the region of inaction from the region of investment. If the general solution is differentiated by M and set equal to κ, we obtain this condition, known as the value-matching condition

(5) $$W_M(M,X)=B_1'(M)X^{\beta_1}+PV_M(M,X)=\kappa.$$

If $B_1(M)X^{\beta_1}$ is interpreted as the value of society's options to invest in institutional reform in the future, then $B_1'(M)X^{\beta_1}$ is the marginal option value that society gives up when it invests in the marginal unit M. The value matching condition states that the lost option value plus the value of the marginal unit of reform must equal the cost of investment. The second condition at the boundary is known as the smooth-pasting condition. It requires that the derivative of $W_M(M, X)$ with respect to X equal the derivative of κ with respect to X at the boundary. Since κ is assumed to be a constant, the smooth-pasting condition is

(6) $$W_{MX}(M,X) = \beta_1 B_1'(M) X^{\beta_1 - 1} + PV_{MX}(M,X) = 0.$$

Combining the value matching and smooth pasting conditions, and eliminating $B_1'(M)$, one can implicitly define the threshold X as a function of M

(7) $$PV_M(M,X) - \frac{X}{\beta_1} PV_{MX}(M,X) = \kappa .$$

Note that

$$PV_M(M,X) = E\left\{ \int_0^\infty N_M(M, X_t) e^{-\rho t} dt \right\}.$$

$N_M(M,X)$ is the net benefit of the Mth unit of market capacity, so $PV_M(M,X)$ is the expected value of this net benefit, given that M is held constant while X_t follows its stochastic process starting from the initial value X. $PV_{MX}(M,X)$ is the marginal effect on this expected value of starting at a higher X. Since a higher X increases the expected value of the marginal unit of capacity, PV_{MX} is positive. Therefore, $PV_M(M,X) > \kappa$. Thus the expected value of the net benefit is greater than the cost at the investment threshold. The excess is the opportunity cost to society of exercising its option to invest in additional market capacity.

Above the Threshold

When (M, X) starts above the threshold curve $W_M(M, X) = \kappa$, the social planner will install a lump of market capacity to move horizontally to the curve. Let M' be the level of market capacity such that (M', X) is on the curve. Then society will jump from M to M' such that

$$W(M, X) = W(M', X) - \kappa[M' - M].$$

Thus, because the social planner will invest instantaneously, $W_M = \kappa$ everywhere above the curve.

Effects of Uncertainty

An increase in uncertainty has three effects. First, an increase in σ will decrease the root ; therefore, the wedge between net benefit and cost will increase. Thus, for any given M, the threshold X increases. Second, an increase in σ will increase μ and δ. This will also increase the threshold X. Third, if $N_M(M, X)$ is a convex function of X, greater uncertainty implies a larger marginal expected present value $PV_M(M, X)$ and therefore a lower threshold, so an increase in σ will discourage investment. Given that the third effect works in the opposite direction of the first two, the net effect will depend on the parameters and the functional forms.

Alternative Investment Policies

The only cost of investment considered thus far is κ, the cost per unit of market capacity expansion. If κ is the only cost, the social planner follows a barrier-control investment policy in which, aside from a potentially large initial investment, she either invests in small bursts at an infinite rate or does not invest at all. If, in addition to κ, there are fixed costs which are independent of the size of the investment, a policy of small, incremental investments will not be optimal. Fixed costs may include, among other things, the costs of negotiating agreements between groups which have vested interests in the status quo. With fixed costs, the optimal investment policy will involve waiting until X rises high enough to justify a large increase in market capacity all at once. This type of "lumpy investment" may also occur as a result of increasing returns to scale in the net benefit function $N(M,X)$, i.e., if a significant number of institutional changes must occur in order to realize any decrease in the cost of trading.

Alternatively, if there are decreasing returns to scale and the cost of investment increases as the *rate* of investment increases, the optimal policy may involve a finite rate of investment over time, as opposed to a "infinite" rate of investment. Costs which increase with the rate of investment are referred to as "adjustment costs." Adjustment costs may stem partially from the difficulty of changing norms of behavior. As Douglass North has argued, the formal "rules of the game" can be changed overnight, but informal norms of behavior only change gradually over time [12]. If the costs associated with institutional change depend on the norms of behavior, i.e. on the actions of water users, bureaucrats, etc., then the costs may increase with the rate of change.

Investment policy may exhibit both lumpy investment and gradual investment if $N_M(M, X)$ is increasing in M over some ranges and then decreasing in M over other ranges. If society is in a region of increasing returns the social planner may invest in multiple institutional changes and thereby jump from the region of increasing to the region of decreasing returns to scale. Then, while in the period of decreasing returns, the social planner may invest gradually. For example, imagine the transition from a world with no water markets to a world with inter-sector markets. There may be increasing returns to scale associated with establishing local markets. Thus society will make a lumpy investment to jump from the initial state with no markets to the transitional state with local markets. Once local markets are established, there may be decreasing returns to scale

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associated with making institutional adjustments in the local-market framework. Eventually, as water scarcity increases, society will make a lumpy investment to jump from local markets to regional markets. Once regional markets are established there may be decreasing returns to scale associated with making institutional adjustments in the regional market framework. Then, as water scarcity increases further, society may make a lumpy investment to jump from regional markets to inter-sector markets, and so on. In the next sections lumpy investment policies and gradual investment policies are explored in more detail.

Consider a more general investment cost function which includes fixed costs and adjustment costs, in addition to the original cost κ.[15] Let the cost of investing dM over the time interval dt be defined as

$$K(dM,dt) = \begin{cases} \Phi + \kappa dM + \Psi(I)dt & \text{if } dM > 0 \\ 0 & \text{if } dM = 0 \end{cases}.$$

The first term Φ is a fixed cost of investment and κdM is the unit investment cost which has been the focus thus far. $I = {}^{dM}\!/_{dt}$ is the rate of investment and $\Psi(I)$dt is the adjustment cost associated with investing at a rate I over the interval dt. It is assumed that $\Psi(0)$dt = 0, $\Psi(I) > 0$ and $\Psi'(I) > 0$ for I > 0.

Now the Bellman equation is

(8)

$$W(M,X) = \max_{dM}\left\{N(M,X)dt + e^{-\rho dt}E\left[W(M+dM, X+dX)\right] - \left[\Phi + \kappa dM + \Psi(I)dt\right]\right\}.$$

If dM > 0, the first-order condition is

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15 A more general cost function of this type is developed by Abel and Eberly [13].

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$$E\left[W_M(M+dM,X+dX)\right]-\kappa-\Psi\left(\tfrac{dM}{dt}\right)=0.$$

In the limit as dt goes to zero the condition becomes

(9) $$W_M(M,X)=\kappa+\Psi'(I),$$

which is the same as the boundary from the original analysis except now there is the additional term $\Psi'(I)$ representing the marginal adjustment costs. When the first-order condition holds, the marginal benefit of an increase in market capacity just equals the marginal cost of the investment.

Because there are fixed costs Φ, a total condition must be evaluated in addition to the marginal condition.

(10) $$E\left[W(M+Idt,X+dX)\right]-\Phi-\kappa Idt-\Psi(I)dt>E\left[W(M,X+dX)\right].$$

The total condition says that the benefit of positive investment, in which $dM = Idt$, must be greater than the benefit of zero investment, in which $dM = 0$. Examining the total condition in the limit as dt goes to zero, one notices that all costs approach zero except the fixed cost Φ. Thu, the inequality will not hold unless $\Phi < 0$, but this is false by assumption. Therefore, if there is a fixed cost, a finite rate of investment cannot be optimal. If the rate of investment were finite, the fixed cost would be incurred at every instant of time over the investment interval, and this would be infinitely costly. With fixed costs the optimal policy will involve discrete investments at isolated instants as with the barrier control policy described above. However, while before the social planner would engage in many small investments to keep (M, X) on the curve $W_M(M,X)=\kappa$, with fixed costs, the social planner will invest less frequently and when she does invest, the additions to market capacity will be larger.

Lumpy Investment

If we assume there are positive fixed costs ($\Phi > 0$) and no adjustment costs ($\Psi'(I) = 0$), investment will be lumpy. In other words, the social planner will invest in many units of market capacity all at once. Investment will also be lumpy if $N_M(M, X)$ is increasing in M. I will explore the case of increasing returns, but the same type of analysis can be used to model stock fixed costs.

Suppose $N_M(M,X)$ is increasing over some range (i.e. increasing investment causes benefits to increase at an increasing rate) and consider two levels of investment M_1 and M_2. Suppose $M_1 < M_2$, and thus $N_M(M_1,X) > N_M(M_2,X)$. Let X_1 and X_2 be the threshold values of X that trigger investment at M_1 and M_2 respectively. If one used equation (7) which was derived under the assumption of decreasing returns to calculate these threshold value, one would conclude that $X_1 > X_2$. In other words assuming that X is rising stochastically over time, the higher investment level M_2 should be undertaken before the lower level M_1. However, the model presumes that if M_2 has been undertaken, earlier investment, i.e. M_1, has already been undertaken. Thus, under increasing returns, the threshold X_1 that justifies the investment M_1 is also high enough to justify the investment M_2 and likewise, the whole range of investment in between. In other words, investment should be lumpy; a whole series of investments should be undertaken at once when a common threshold is reached.

Suppose returns to investment are initially increasing and then decreasing. If society begins in the increasing returns region, the level of X that triggers investment and the size of the jump which occurs will depend on the initial level of M. Compare two levels of M in the increasing returns range, M_1 and M_2, where $M_1 < M_2$. It can be shown that if investment takes place, the jump associated with M_1 will be larger than the jump associated with M_2. However, $X_1 > X_2$; the level of X necessary to trigger investment from the initial point M_1 will be higher than the level necessary to trigger investment from the initial point M_2.[16]

Gradual Investment

In this section I assume that fixed costs are zero. Without fixed costs, the first-order condition $W_M(M, X) = \kappa + \Psi'(I)$ determines the rate of investment as a function of the state variables. The curve defined by the first-order condition can be interpreted as society's demand curve for additional market capacity. At any instant the current state (M, X) is known and therefore $W_M(M, X)$ can be evaluated. This is the marginal increase in net social benefit that would result if society had an additional unit of market capacity. A rate of investment I sustained over a short time interval dt contributes the marginal amount Idt to market capacity. The first-order condition sets the marginal benefit of this investment equal to the marginal cost. The rate of investment becomes positive when the marginal benefit $W_M(M, X)$ rises to $\kappa + \Psi'(0+)$. As the marginal benefit rises further, the rate of investment will increase so the first order condition remains satisfied.

If $\kappa = 0$ and $\Psi'(0+) = 0$, there is no period of inaction. The social planner will invest as soon as W_M becomes positive, and as W_M increases, the rate of investment will increase. If $\kappa = 0$ but $\Psi'(0+) > 0$, the social planner will invest as soon as $W_M(M, X) = \Psi'(0+)$. If $\kappa > 0$ but $\Psi'(I)$ is approximately zero for all I, i.e., adjustment costs are insignificant, the social planner returns to the original barrier control policy.

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16 A good example of lumpy investment is the overnight development in 1991 of California's Emergency Drought Water Bank. The Bank was created in response to the crisis of the drought, but it has since

If (M, X) is in a region where the rate of investment is positive, the Bellman equation is

$$(11) \quad W(M,X) = \max_{dM}\left\{N(M,X)dt + e^{-\rho dt}E\left[W(M+dM, X+dX)\right] - \left[\kappa dM + \Psi(I)dt\right]\right\}$$

Then, expanding the right-hand side using Ito's Lemma, we get

$$W(M,X) = N(M,X)dt + (1-\rho dt)\left[W(M,X) + \alpha X W_x(M,X)dt + \tfrac{1}{2}\sigma^2 X^2 M_{xx}(M,X)dt + IW_M(M,X)dt - \kappa I dt - \Psi(I)dt\right]$$

Keeping terms to order dt

$$= W(M,X) + \left[\tfrac{1}{2}\sigma^2 X^2 W_{xx}(M,X) + \alpha X W_x(M,X) - \rho W(M,X) + IW_M(M,X) - \kappa I - \Psi(I) + N(M,X)\right]dt$$

Then $W(M, X)$ solves the partial differential equation

(12)

$$\tfrac{1}{2}\sigma^2 X^2 W_{xx}(M,X) + \alpha X W_x(M,X) - \rho W(M,X) + IW_M(M,X) - \kappa I - \Psi(I) + N(M,X) = 0$$

Application to the CVP and C-BT

This model can be used to analyze institutional investment decisions in the CVP and C-BT. If one argues that the C-BT has a higher current level of market capacity than the CVP, then $M_{\text{C-BT}} > M_{\text{CVP}}$. In addition, costs and benefits of reform are different for each project, *i.e.* $K_{cvp}(dM,dt) \neq K_{cbt}(dM,dt)$ and $N_{cvp}(M,X) \neq N_{cbt}(M,X)$. If the C-BT is in an area of decreasing returns to investment and the CVP is in an area of increasing returns, incremental investment may be triggered in the C-BT before any investments are undertaken in the CVP. However, once X finally rises high enough to trigger investment in the CVP, significant reform may occur all at once due to the increasing returns to

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become a permanent institution [6].

investment. It is conceivable that the CVP could thus “leapfrog” past the C-BT such that $M_{\text{CVP}} > M_{\text{C-BT}}$.

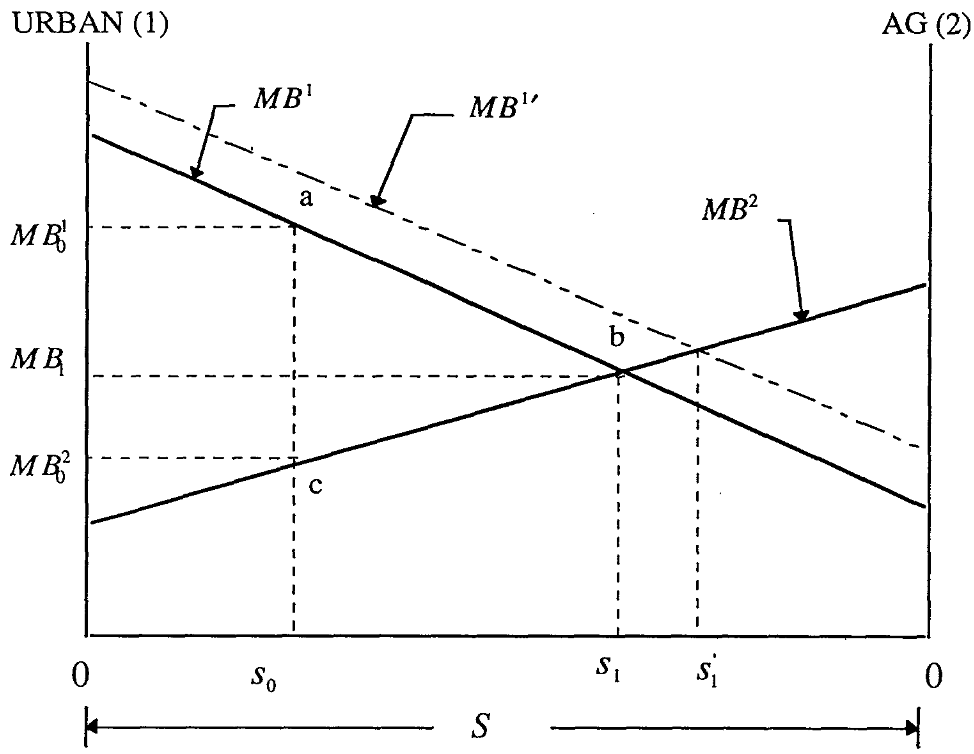

FIGURE 1. *When Ag sells s_1 - s_0 to Urban, $MB_1^1 = MB_1^2$. Dotted line shows effect of increase in Urban demand.*

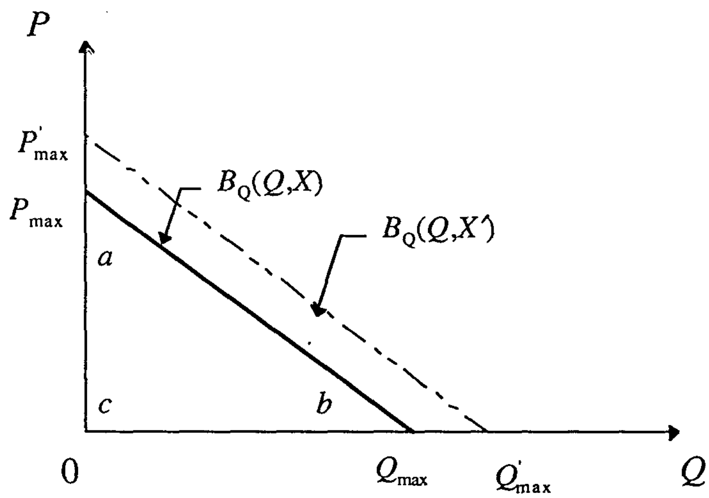

FIGURE 2. *Marginal benefit from trade between Urban and Ag. $B_Q(\cdot)$ shifts out when excess demand increases to X'.*

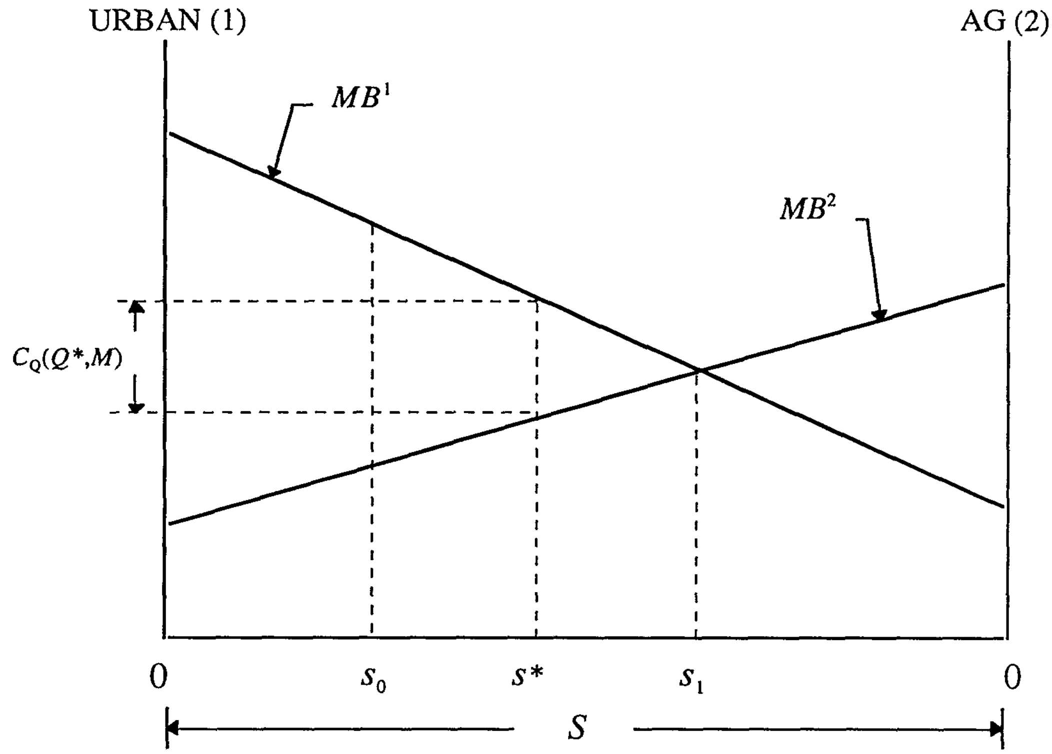

FIGURE 3. *With transaction costs, Ag only sells $s^* - s_0$ to Urban. At s^*, $MB^1 = MB^2 + C_Q(Q^*,M)$.*

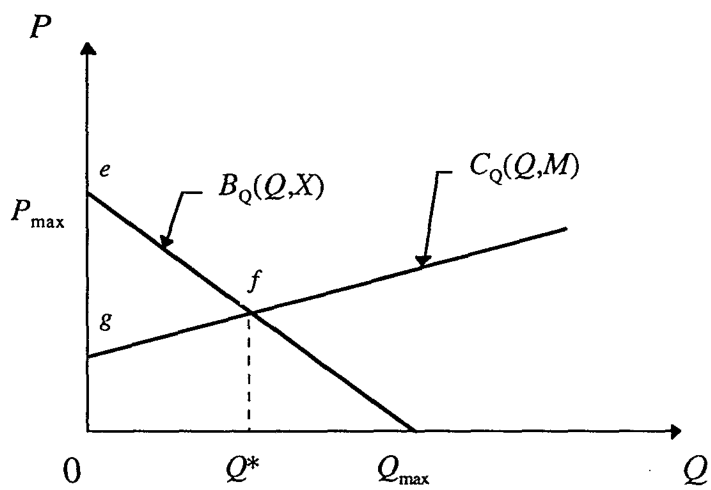

FIGURE 4. *At Q^*, the marginal benefit of trading equals the marginal cost.*
the marginal cost.

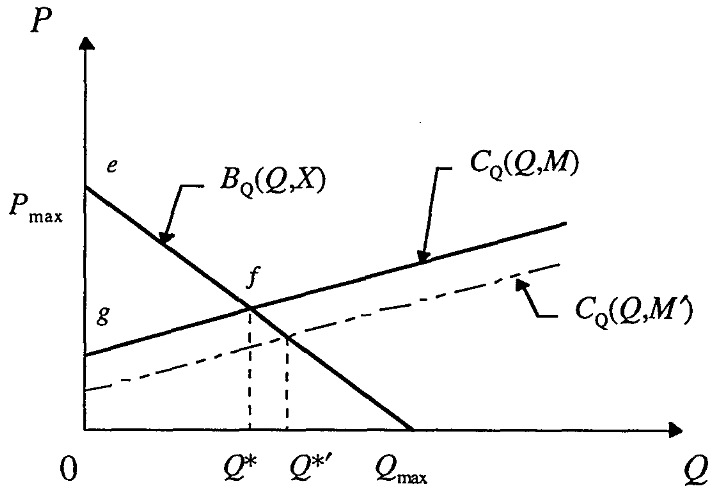

FIGURE 5. *Institutional reform, represented by an increase from M to M′, shifts the transaction cost curve down.*

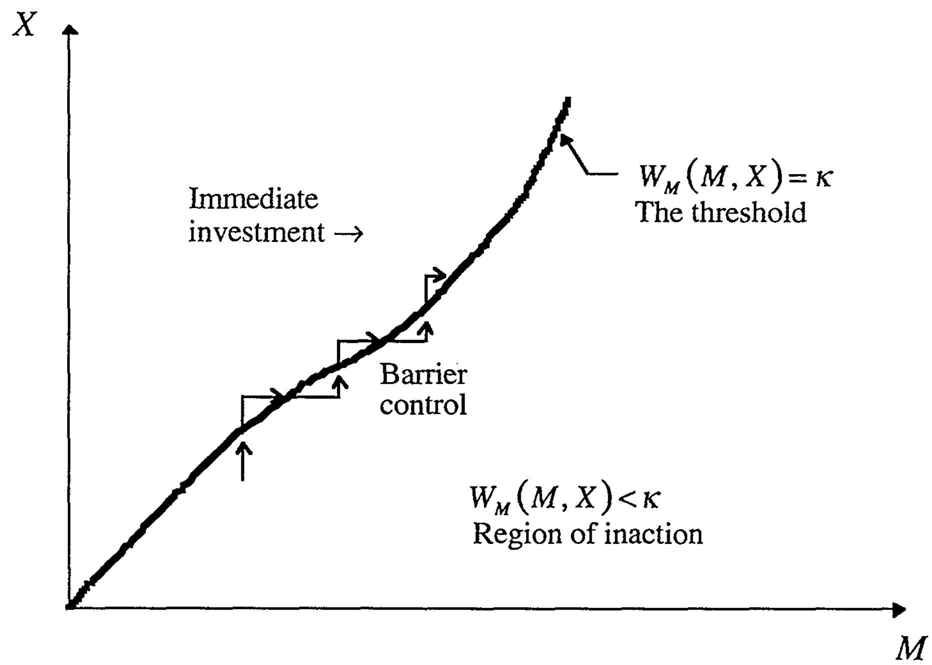

FIGURE 6. *The threshold $W_M(M,X)=\kappa$ separates the region of inaction from the region of investment.*

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